



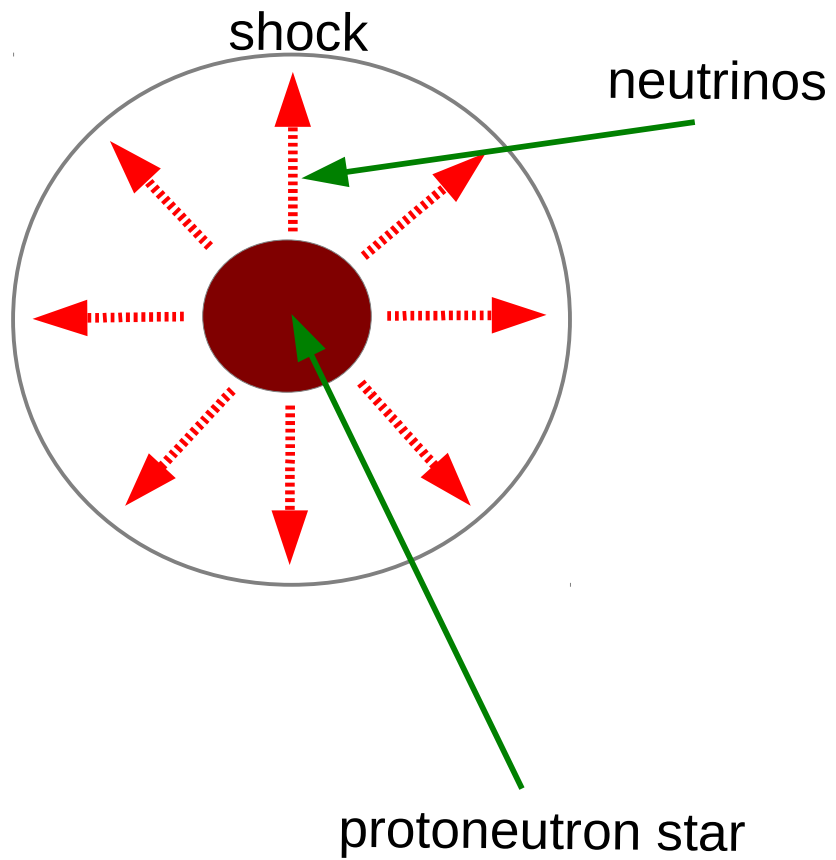
# General Relativistic Simulations Three-dimensional of Core-collapse Supernovae

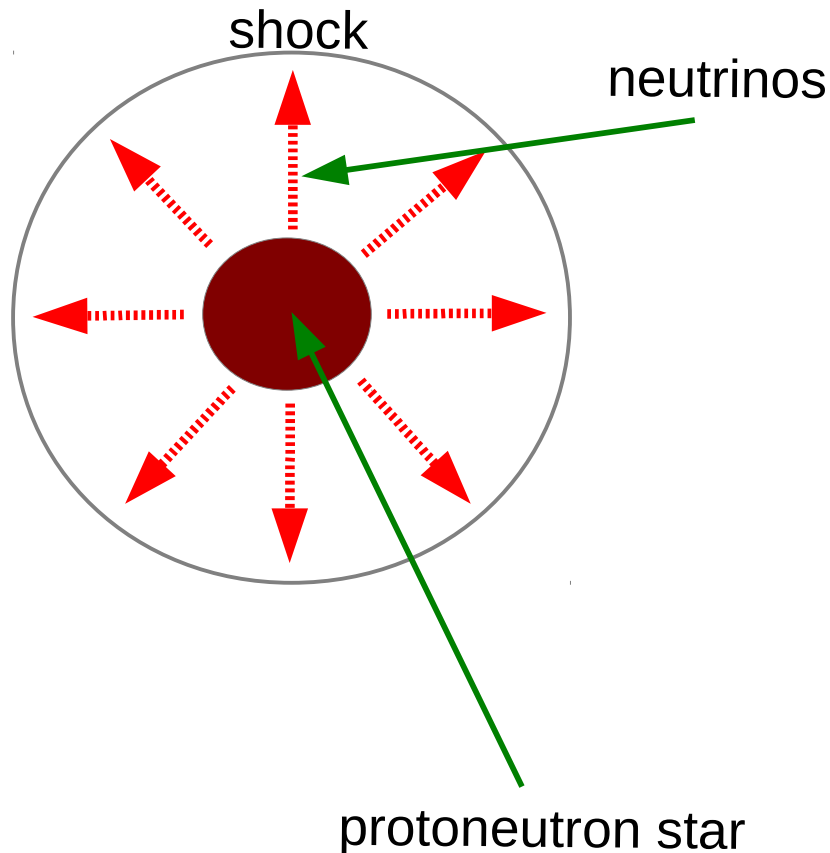
Ernazar Abdikamalov

Caltech

Collaborators:

C. D. Ott, R. Haas, P. Mösta, C. Reisswig, E. Schnetter



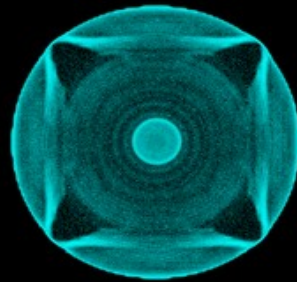


- 1D: no explosion in massive stars [Liebendörfer+01, Rampp & Janka 02, etc.]
- 2D: explosions aided by **SASI** and **convection** [Blondin & Mezzacappa 03, Müller+12, Fernandez 10, Foglizzo+06, Murphy & Burrows 08, etc.]
- What happens in 3D? [Burrow+12, Couch+13, Hanke+13, Ott+13, Takiwaki+13, etc.]

# $27M_{\text{Sun}}$ progenitor (by Woosley+02)

- Müller+12: strong SASI and weak convection in 2D.
- Ott+13: weak SASI and strong convection in 3D.

5.93 ms



# $27M_{\text{Sun}}$ progenitor (by Woosley+02)

- Müller+12: strong SASI and weak convection in 2D.
- Ott+13: weak SASI and strong convection in 3D.
- Hanke+13: strong SASI in 3D.

# Why different results?

- Grid perturbations? [Scheck+08]
- Neutrino heating rate? [leakage vs. full transport]

# New simulations with minimized grid perturbations

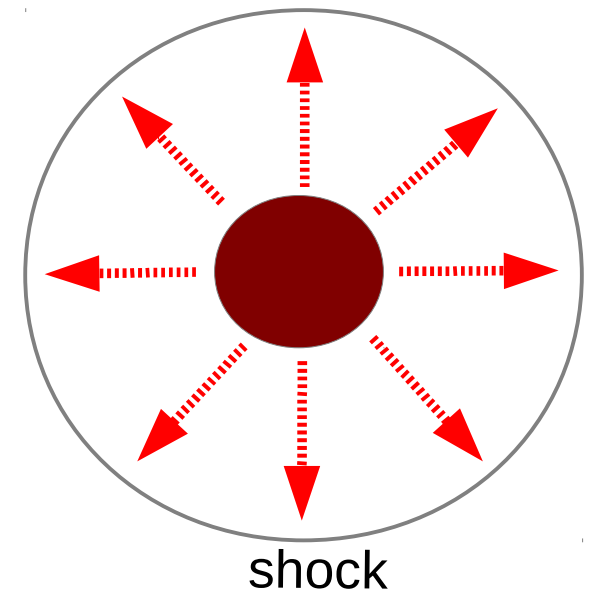
- Evolve in **1D** until shock almost stalls (GR1D code by O'Connor & Ott 2010)
- Use the final **1D** data for subsequent **3D** evolution (no shock crossing of refinement level boundaries)
- 3D evolution: reconstruction
  - **PPM** near the shock (more dissipation) [Colella & Woodward 84]
  - **Enhanced PPM** elsewhere (less dissipation) [Colella & Sekora 08]



# Models

- Heating factors:
  - 1.05 (strong heating)
  - 0.8 (weak heating)
  - 0.5 (negligible heating)
- Different numerical resolutions

$$\text{Heating} \propto f_{\text{heat}} L_{\nu}$$

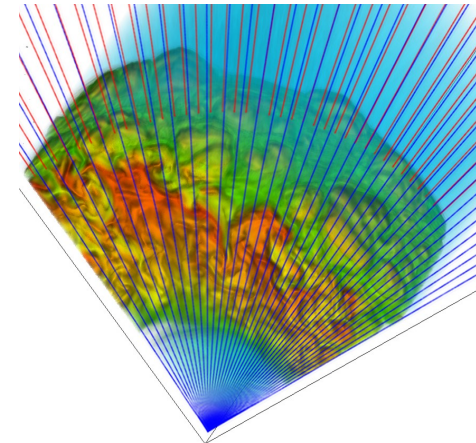
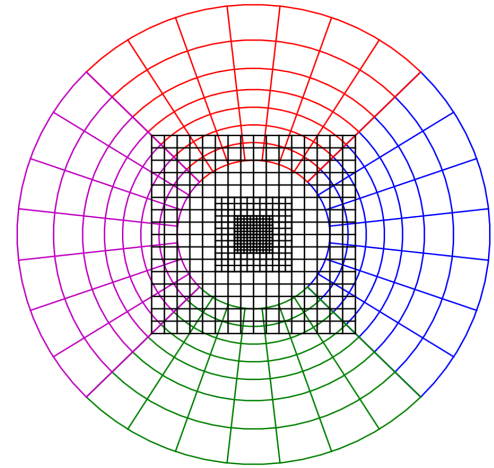
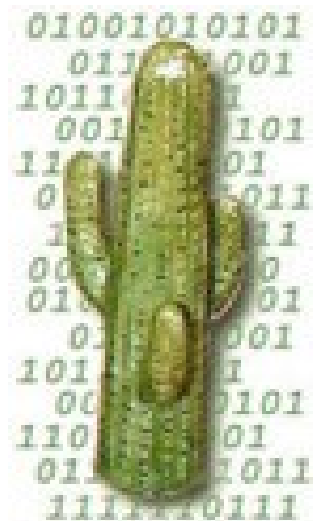




# 3D Code: Einstein Toolkit

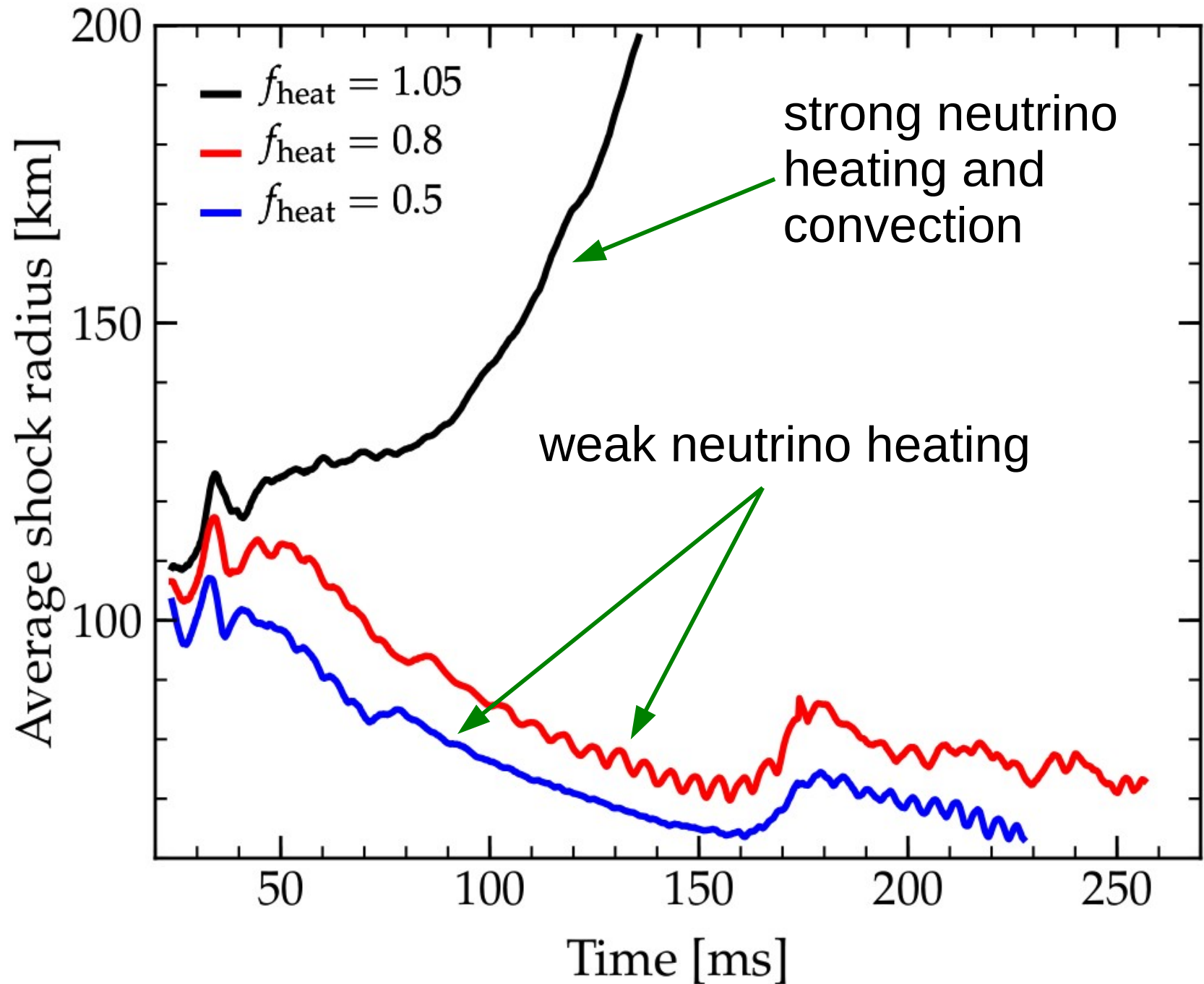
`einsteintoolkit.org`, `stellarcollapse.org`

- Infrastructure (**Cactus**)
- General relativity (**CTGamma**)
- Hydrodynamics (o/e PPM, **GRHydro**)
- 3D AMR+multipatch (**Carpet+Llama**)
- Neutrino leakage/heating (**Zelmani**)
- LS220 EOS

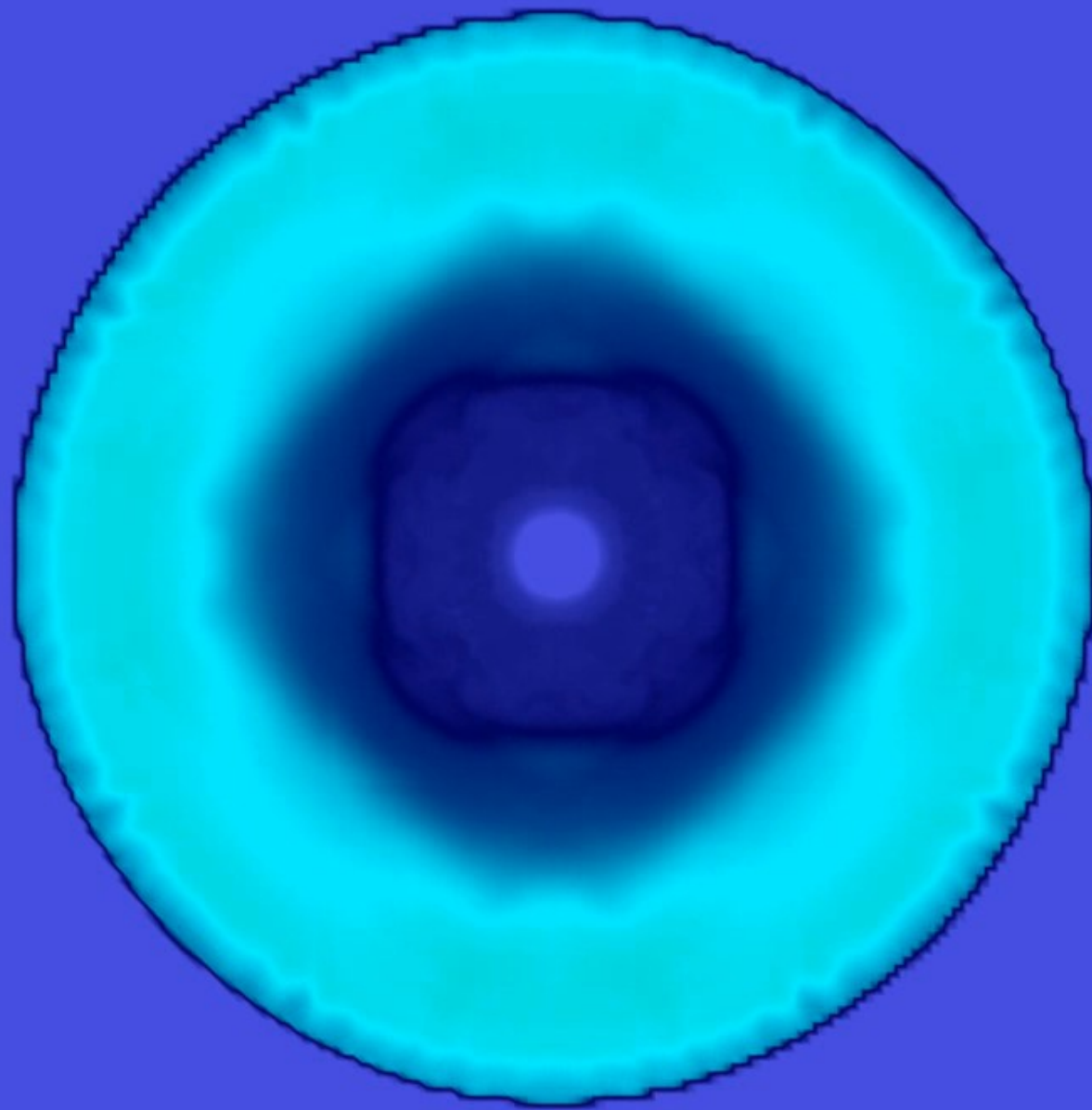


More info: Ott, EA+12,13, Reisswig+13, Mösta+13, O'Connor&Ott 11

# Results: dependence on heating

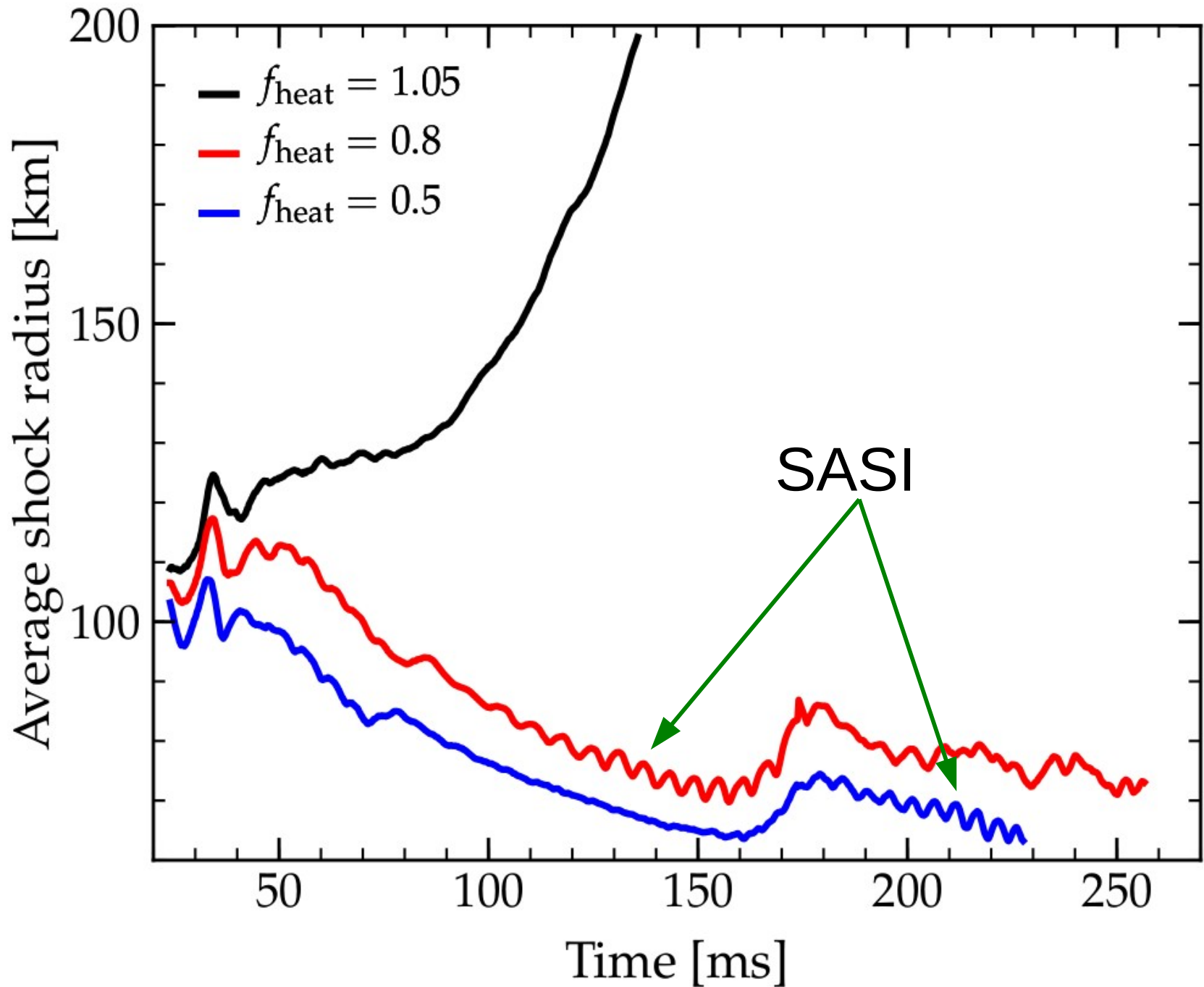


Time since bounce: 34.53 ms

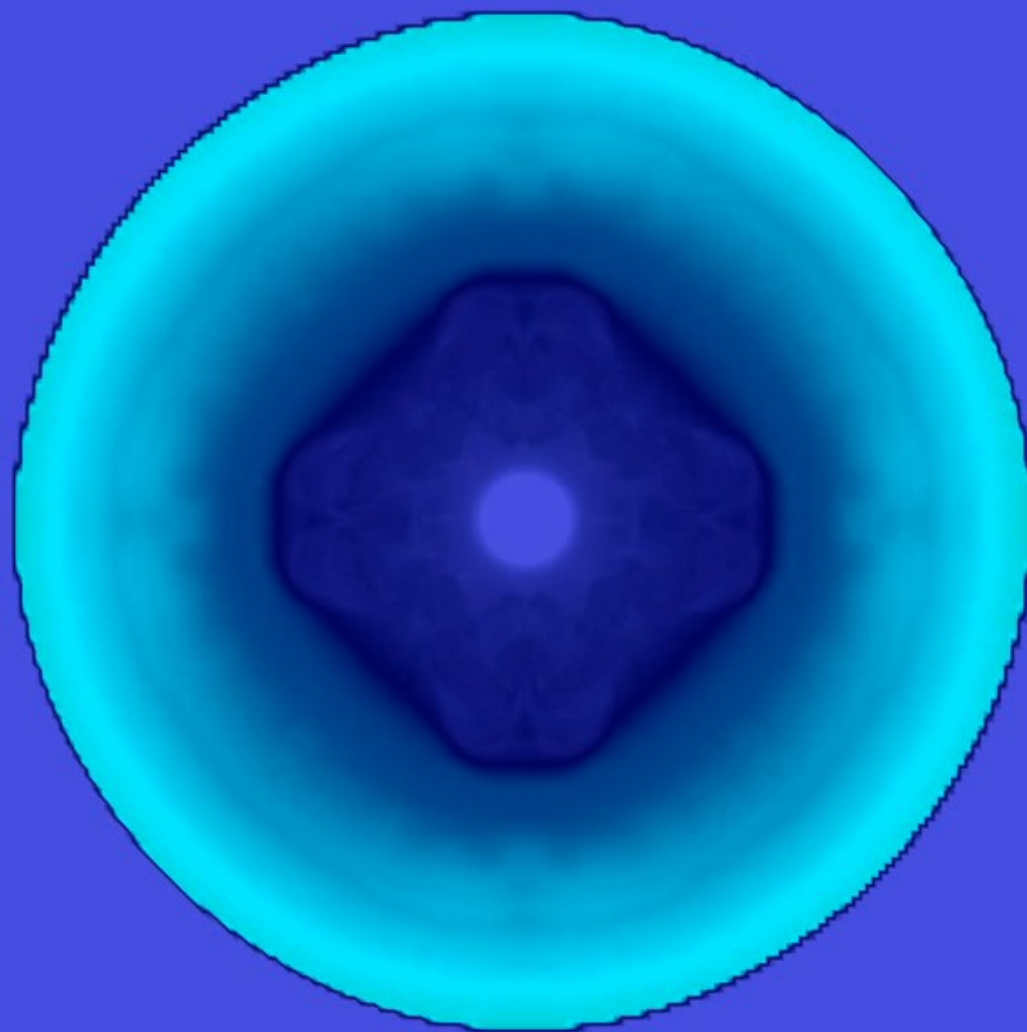


Strong heating  $\leftrightarrow$  convection

# Results: dependence on heating



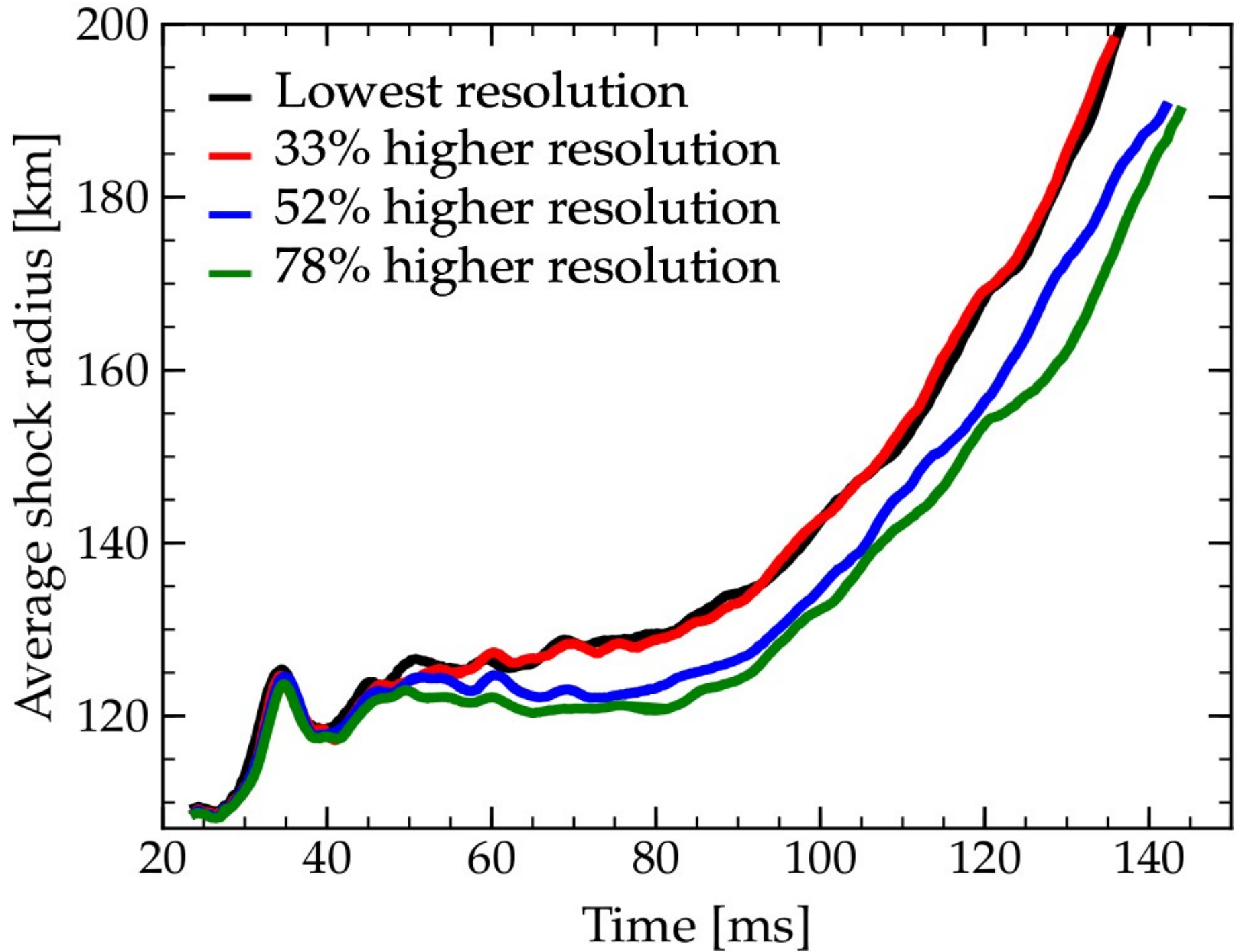
Time since bounce: 30.90 ms



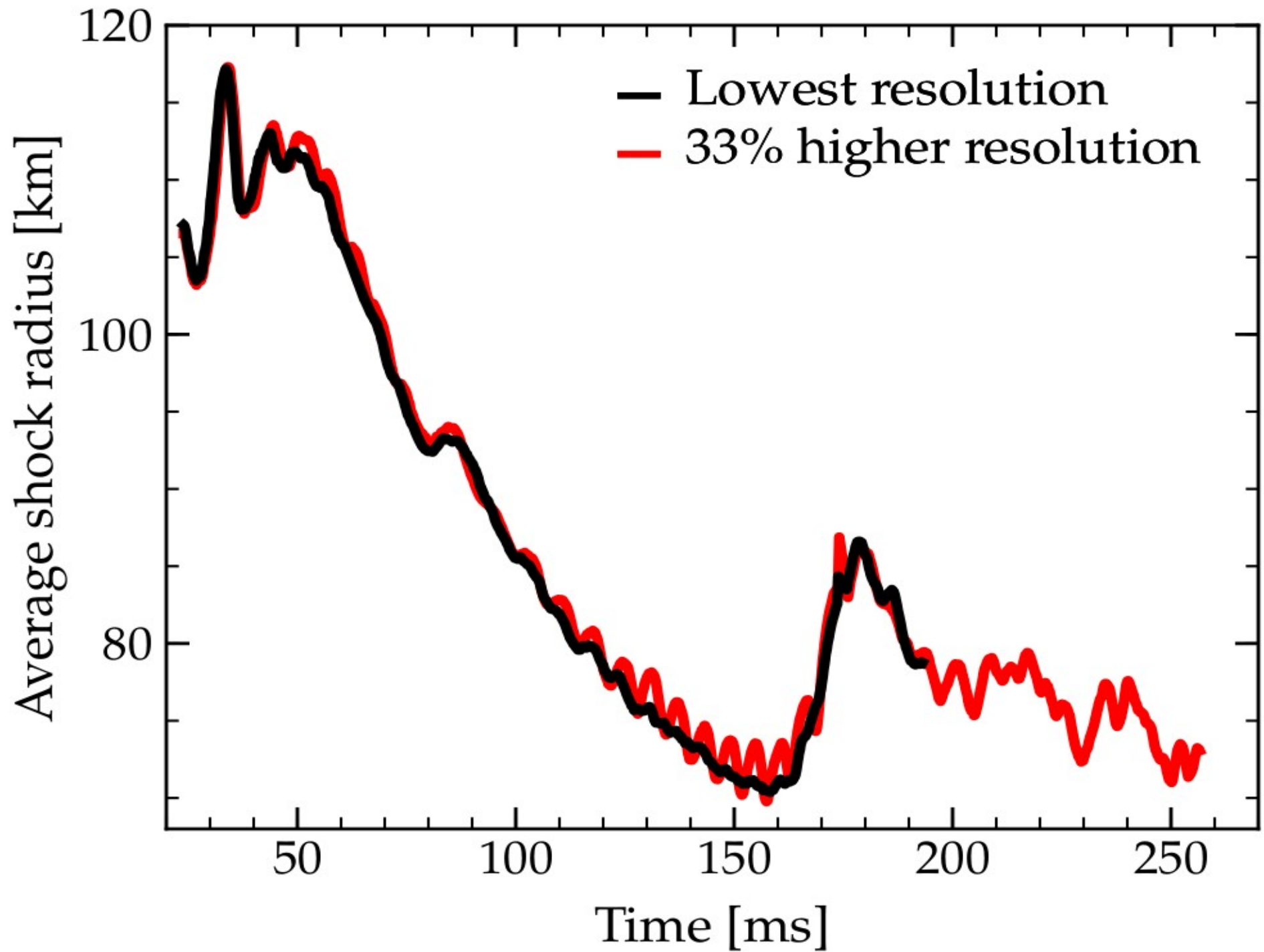
Weak heating  $\leftrightarrow$  SASI



# Strong heating: resolution study



# Weak heating: resolution study



# Conclusions

- 3D GR simulations of s27 model
- Strong convection with high heating
- Strong SASI with weak heating
- Resolution dependence